MODEL IN THE LOOP SIMULATION OF AN ACTIVE FRONT WHEEL STEERING SYSTEM FOR WHEELED ARMORED VEHICLE

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ABSTRACT

During firing on the move, handling performance of an armored vehicle will be affected which causing it to lose its directional stability. This is due to an impulse force created at the center of gun turret, which produce an unwanted yaw moment at the center of gravity (COG) of the armored vehicle. The unwanted yaw motion created cause the directional stability of the armored vehicle is violated where it will sway from its intended path without any input from driver. To reject the unwanted yaw moment in purposed to improve the handling ability of the armored and also to make it able to perform firing while moving, this study deals with proposing a new Active Front Wheel Steering (AFWS) system actuator which consists of Ravigneaux planetary gear which was previously applied in automotive transmission system. This study focused on developing a control strategy for the AFWS system in order to reduce unwanted yaw motion created by armored vehicle during the execution of firing using gun turret system. This study also includes the explanation of the design, working principle and the derivation of the planetary gear mathematical model based on its dynamic behavior. The mathematical model is validated with the actual system to assess the model validity. The proposed AFWS actuator is then implemented into Pitman arm steering system test rig to analyze its robustness and functionality using position tracking control method. The position tracking control method is conducted using Model-in-Loop simulation which consists of Software-in-Loops simulation (SILs) and Hardware-in-Loop simulation (HILs). SILs is applied to the position tracking control in order to validate the mathematical model developed while HILs is used to test the functionality of the proposed AFWS actuator in actuating the steering system. The proposed control strategy consists of PI controller tuned by neural network system which is named as Neuro-PI controller. The Neuro-PI controller is optimized by Genetic algorithm optimization tools to obtained the most optimum activation function to be applied in the neural network system. The optimum neural system is selected based on its performance in controlling the handling stability of armored vehicle in reducing the unwanted yaw motion. The Neuro-PI controller with *Hardlims* activation function shows a better performance which able to reduce up to 40% of unwanted yaw motion compared to other activation function. The robustness of the optimum controller is tested using HILs together with the implementation of the proposed AFWS actuator. The result from the experiment shows that both the proposed AFWS actuator and the controller can be applied in the armored vehicle to improve the handling stability by reducing the yaw motion produced during the execution of firing while in motion.

ABSTRAK

Dalam melaksanakan penembakan semasa pergerakan, pelaksanaan pengendalian sesuatu kenderaan perisai akan terjejas yang menyebabkan ia kehilangan kestabilan arah. Ini adalah kerana daya dorongan wujud di tengah-tengah turet, yang menghasilkan kadar yaw yang tidak diingini di pusat graviti (COG) kenderaan perisai tersebut. Kajian ini berkaitan dengan cadangan untuk menghasilkan penggerak baru bagi sistem stereng hadapan aktif yang terdiri daripada planet gear *Ravigneaux* di mana sebelum ini ianya digunakan sebagai sistem transmisi di dalam bidang automotif. Kajian ini juga termasuk penjelasan dalam hal reka bentuk, prinsip kerja dan penghasilan model matematik untuk planet gear tersebut berdasarkan tingkah laku dinamik gear itu sendiri. Model matematik tersebut disahkan dengan sistem sebenar untuk menilai kesahihan model matematik yang dihasilkan. Pengerak stereng hadapan aktif yang dicadangkan dilaksanakan ke dalam sistem pelantar *Pitman arm*. Kajian ini dilanjutkan dengan menganalisis keteguhan dan tahap fungsi penggerak tersebut dengan menggunakan kaedah pengesanan kawalan kedudukan. Kaedah pengesanan kawalan kedudukan dijalankan menggunakan simulasi *Model-in-Loop (MiLs*) di mana terdiri daripada simulasi *Software-in-Loop* (SILs) dan simulasi *Hardware-in-Loop (HILs)*. Dalam eksperimen mengesan kawalan kedudukan, SILs digunakan sebagai pengesahan model matematik yang telah dihasilkan. Manakala tujuan HILs digunakan untuk menguji kemampuan penggerak stereng hadapan aktif yang dicadangkan dalam menggerakkan sistem stereng. Selain itu, kajian ini juga memberi tumpuan kepada penghasilan strategi kawalan untuk sistem stereng hadapan aktif yang bertujuan mengurangkan gerakan rewang yang tidak diingini yang terwujud dalam kenderaan berperisai semasa perlaksanaan tembakan menggunakan sistem senjata turet. Strategi kawalan yang dicadangkan itu terdiri daripada pengawal PI ditala oleh sistem rangkaian neural yang diberi nama sebagai pengawal Neuro-PI. Pengawal Neuro-PI dioptimumkan oleh *Genetic Algorithm*. Pengoptimuman tersebut bertujuan untuk mendapatkan fungsi pengaktifan yang paling optimum untuk diaplikasikan dalam sistem rangkaian steering hadapan aktif. Pengawal Neuro-PI dengan fungsi pengaktifan *Hardlims* menunjukkan prestasi yang lebih baik di mana ia mampu mengurangkan sehingga 40% daripada gerakan yaw tidak diingini berbanding fungsi pengaktifan lain. Keteguhan pengawal yang paling optimum diuji menggunakan HILs bersama-sama dengan penggerak stereng hadapan aktif yang dicadangkan. Hasil daripada eksperimen menunjukkan bahawa kedua-dua cadangan penggerak stereng hadapan aktif dan pengawal *Neuro-PI* boleh digunakan dalam kenderaan berperisai untuk meningkatkan kestabilan pengendalian dengan mengurangkan pergerakan rewang yang tidak diingini terhasil semasa perlaksanaan tembakan semasa bergerak.

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APPROVAL

I certify that an Examination Committee has met on **10th NOVEMBER 2016** to conduct the final examination of **MAZUAN BIN MANSOR** on his degree thesis entitled '**MODEL IN THE LOOP SIMULATION OF AN ACTIVE FRONT WHEEL STEERING SYSTEM FOR WHEELED ARMORED VEHICLE'.** The committee recommends that the student be awarded the degree of Master of Science (Mechanical Engineering).

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This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science (Mechanical Engineering). The members of the Supervisory Committee were as follows.

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LIST OF ABBREVIATION AND SYMBOLS

a_x	Longitudinal acceleration
a_y	Lateral acceleration
$\dot{\gamma}$	Vehicle yaw rate
α_f	Front wheel slip angle
α_r	Rear wheel slip angle
δ_s	Sun gear angle
δ_c	Ring gear angle
δ_p	Planet gear angle
T_{ai}	Wheel acceleration torque
T_{bi}	Wheel brake torque
Y_r	Transitional displacement of the steering rack
δ_{SLU}	Rotational displacement of upper steering linkage
δ_{SLL}	Rotational displacement of lower steering linkage
T_K	Kingpin torque
B_{SL}	Lower steering column viscous damping coefficient
r_p	Length of Pitman arm member
B_R	Steering linkage viscous damping

CF_r	Coulomb friction breakout force on steering linkage
CF_{FW}	Coulomb friction breakout force on road wheel
K_t	Tire spring constant
r_s	Sun gear radius
r_{pi}	Planet gear radius
r_c	Ring gear radius
F_f	Firing force
C_d	Damper constant
F_d	Damper force
F_s	Spring force
F_x	Longitudinal force
F_y	Lateral force
K_s	Spring constant
k_a	Gear meshing stiffness
m_s	Sprung mass
m_u	Unsprung mass
AFWS	Active Front Wheel Steering
b	bias
CARSIM	Car simulator software
DAQ	Data acquisitions
DLC	Double lane change

DOF	Degrees of freedom
G	PID controller
GA	Genetic algorithm
Hardlims	Hard-limit transfer function
HIL	Hardware-in-Loop
HMMWV	High mobility multipurpose wheeled vehicle
MATLAB	Matrix Laboratory software
Netinv	Inverse transfer function
PID	Proportional, integral and derivative controller
RMS	Root mean square
SIL	Software-in-Loop
xPC	PC target

CHAPTER 1

INTRODUCTION

1.1 Overview

An armored vehicle is one of battle vehicles shielded by strong armor and most of them are armed with weapons. Thus, this combination made the vehicle to be operational in terms of tactical offensive and also defensive capabilities. In fact, armored vehicle is an embodiment of a unique combination of firepower, mobility and protection (R. Steeb *et. al.*, 1991). The armored vehicle is classified according to its function on the battlefield and also fitted with light, medium and heavy armored depending on its role. The general design attributes are meant to contribute in protecting the troops against mines or blast due to the attacks from the enemy

Another important criterion concerned in developing armored vehicle is the type of wheel where it can be divided into two categories: wheeled and tracked armored vehicle. Both types give different advantages in terms of mobility, survivability and supportability.

P. Hornback, (1998) discusses the advantages and disadvantages of the wheeled and tracked armored vehicle which is summarized in Table 1.1.

Table 1.1 Comparison between wheeled and tracked armored vehicle

	Tracked	**wheeled**
Mobility	Better mission travel time off-road and suitable for all weather.	Attain fast road speed on-road but acquired longer time for off-road.
Survivability	More compact but the reduction in agility and the bigger size cause it to be easily targeted by the enemy.	More vulnerable to small arms, grenade and mines but great in agility and not easily targeted by enemy.
Supportability	Off-road usage and greater in weight cause higher fuel consumption to provide higher engine torque.	Better fuel economy due to reduced friction in wheel suspension, required less maintenance and supply support.

Although tracked armored vehicle precedes in providing optimal solution for tactical, high-mobility off-road and to achieve restricted road profile mission and also better in survivability but wheeled armored vehicle is providing more desirable handling performance as well as it has better agility during combat.

Vehicle handling is a description of the way that wheeled armored vehicles perform transverse to their direction of motion, particularly during cornering and swerving. During a normal driving, tires of the wheeled armored vehicle remain within linear ranges of operation, where lateral forces of tire increase proportionally to tire slip angles.

Consequently, the vehicle yaw rate is proportional to the steering angle at a given velocity. This linear and consistent response of the vehicle to driver steering inputs is violated when tires approach or arrive at the limit of adhesion, as may occur during emergency handling maneuvers or during riding on slippery roads. In these conditions, vehicle handling characteristics change quite quickly compared to what the driver is accustomed to, making it unmanageable for an average driver to hold mastery of the vehicle. Due to the problem, it becomes a limitation for the armored vehicle to perform an agile offensive ability tactical such as executing a firing while the vehicle is moving.

1.2 Background of the study

Recently, wheeled armored vehicles such as shown in Figure 1.1 are facing external disturbances such as rough off-road terrain, impulse force from gun firing, side wind force and un-uniform tire grip in all four tires. Hence, it requires good maneuverability, a strong driving force, stability and ride comfort to overcome the problems affecting the vehicle while in motion (Hudha *et. al*., 2012). By considering the dynamics of ground vehicles, yaw motion that occur in a vehicle can be categorized as desired and actual yaw motions. Desired yaw motion is yaw motion needed by the driver while cornering which means it follows the driver's steering input, while actual yaw motion occurs when direction of the vehicles begin to change without any steer input from the driver. An unwanted yaw motion which occurs through external disturbances can be a contributing factor of vehicle accidents since the directional stability of the vehicle decreases abruptly. Additionally, this factor also causes the driver to lose control of the vehicle.